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(54) **Title:** SCINTILLATION PIXEL ARRAY, RADIATION SENSING APPARATUS INCLUDING THE SCINTILLATION PIXEL ARRAY AND A METHOD OF FORMING A SCINTILLATION PIXEL ARRAY

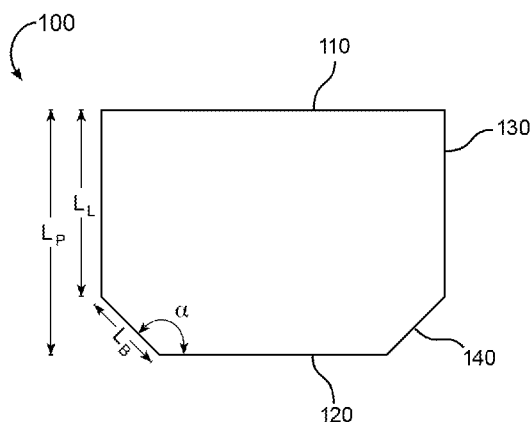


FIG. 1

(57) **Abstract:** The disclosure relates to a scintillation pixel array, a radiation sensing apparatus, a scintillation apparatus, and methods of making a scintillation pixel array wherein scintillation pixels have beveled surfaces and a reflective material around the beveled surfaces. The embodiments described herein can reduce the amount of cross-talk between adjacent scintillation pixels.

SCINTILLATION PIXEL ARRAY, RADIATION SENSING APPARATUS INCLUDING THE SCINTILLATION PIXEL ARRAY AND A METHOD OF FORMING A SCINTILLATION PIXEL ARRAY

FIELD OF THE DISCLOSURE

5 This disclosure relates to scintillation pixel arrays, radiation sensing apparatuses, and methods of making a scintillation pixel array.

DESCRIPTION OF RELATED ART

Scintillator-based detectors are used in a variety of applications, including research in nuclear physics, oil exploration, field spectroscopy, container and baggage scanning, and medical diagnostics.

10 When a scintillator material of the scintillator-based detector is exposed to a particular radiation, the scintillator material captures energy of incoming radiation and scintillates, re-emitting at least some of the absorbed energy in the form of photons. Further improvements of scintillator-based detectors are desired.

BRIEF DESCRIPTION OF DRAWINGS

15 Embodiments are illustrated by way of example and are not limited by the accompanying figures.

FIG. 1 illustrates a cross section of a scintillation pixel in accordance with an embodiment described herein.

20 **FIG. 2** illustrates a cross section of a scintillation pixel and a reflective material in accordance with an embodiment described herein.

FIG. 3 illustrates a cross section of a scintillation pixel and a reflective material in accordance with an embodiment described herein.

FIG. 4 illustrates a cross section of a scintillation pixel and a reflective material in accordance with an embodiment described herein.

25 **FIG. 5** illustrates a perspective view of a scintillation pixel in accordance with an embodiment described herein.

FIG. 6 illustrates a cross section of a scintillation pixel in accordance with an embodiment described herein.

30 **FIG. 7** illustrates a perspective view of a scintillation pixel array in accordance with an embodiment described herein.

FIG. 8 illustrates a perspective view of a scintillation pixel array and a reflective material in accordance with an embodiment described herein.

FIG. 9 illustrates a schematic of a radiation sensing apparatus in accordance with an embodiment described herein.

35 **FIG. 10** illustrates a schematic of a radiation sensing apparatus including a mask in accordance with an embodiment described herein.

FIG. 11 illustrates simulation results using a scintillation pixel array without a beveled surface.

FIG. 12 illustrates simulation results using a scintillation pixel array having beveled surfaces.

Skilled artisans appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures can be exaggerated relative to other elements to help improve understanding of embodiments of the invention. The use of the same reference symbols in different drawings indicates similar or identical items.

DETAILED DESCRIPTION

The following description in combination with the figures is provided to assist in understanding the teachings disclosed herein. The following discussion will focus on specific implementations and embodiments of the teachings. This focus is provided to assist in describing the teachings and should not be interpreted as a limitation on the scope or applicability of the teachings.

As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having,” or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of features is not necessarily limited only to those features but can include other features not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, “or” refers to an inclusive-or and not to an exclusive-or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

The use of “a” or “an” is employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural, or vice versa, unless it is clear that it is meant otherwise.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples are illustrative only and not intended to be limiting. To the extent not described herein, many details regarding specific materials and processing acts are conventional and can be found in textbooks and other sources within the scintillation and radiation detection arts.

A scintillation pixel array and a radiation sensing apparatus can include a plurality of beveled scintillation pixels and a reflective material disposed about the scintillation pixel. In a particular aspect, the reflective material covers less than approximately 99% of the beveled surface. In another aspect, the reflective material extends laterally about the beveled surfaces thereby creating void space. In another aspect, the reflective material can be disposed along substantially none of the beveled

surfaces. Cross-talk between scintillation pixels is thus improved to an unexpectedly large degree. Non-limiting embodiments as described below help to provide a better understanding of the concepts described herein

FIG. 1 illustrates a scintillation pixel **100** in accordance with an embodiment. The scintillation pixel **100** can have a proximal end **110**, a distal end **120** opposite the proximal end **110**, a longitudinally extending surface **130** adjacent the distal end, and a beveled surface **140** between the distal end **120** and the longitudinally extending surface **130**. The scintillation pixel **100** can have four longitudinally extending surfaces **130** and four beveled surfaces **140** between the four longitudinally extending surfaces **130** and the distal end **120**. Each of the distal end **120** and the proximal end **110** can have four sides. In an embodiment, the scintillation pixel can take the form of a polygon having a substantially flat surface at the distal end **120** and proximal end, four longitudinally extending surfaces adjacent a respective side of the proximal end, and four beveled surfaces extending between a respective of side of the distal end **120** and a respective longitudinally extending surface **130**. In certain other embodiments, the scintillation pixel **100** can have a variety of different shapes. For example, in certain embodiments, the scintillation pixel **100** can have less than or more than four surfaces. The beveled surface can form an angle α of approximately 135° with the distal end **120**. In certain embodiments, the beveled surface **140** can form an angle α of greater than approximately 90° , greater than approximately 105° , greater than approximately 120° , or greater than approximately 130° with the distal end **120**. In certain embodiments, the beveled surface **140** can form an angle α of less than approximately 180° , less than approximately 165° , less than approximately 150° , or less than approximately 140° with the distal end **120**. In certain embodiments, the beveled surface **140** can form an angle α of from greater than 90° to less than 180° , from approximately 105° to approximately 165° , from approximately 120° to approximately 150° , or from approximately 130° to approximately 140° with the distal end **120**.

The beveled surface **140** can have a length L_B , and the scintillation pixel **100** can have a length L_P . In certain embodiments, a ratio of the length of the beveled surface L_B to the length of the scintillation pixel L_P can be greater than approximately 1:10, greater than approximately 1:8, or greater than approximately 1:6. In certain embodiments, a ratio of the length of the beveled surface L_B to the length of the scintillation pixel L_P can be of less than approximately 1:2, less than approximately 1:3, or less than approximately 1:4. A ratio of the length of the beveled surface L_B to the length of the scintillation pixel L_P can be in a range of approximately 1:10 to approximately 1:2, from approximately 1:8 to approximately 1:3, or from approximately 1:6 to approximately 1:4.

In certain embodiments, the beveled surface **140** can have a length L_B of greater than approximately 0.1 mm, greater than approximately 0.5 mm, or greater than approximately 1 mm. In certain embodiments, the beveled surface **140** can have a length L_B of less than approximately 25 mm, less than approximately 15 mm, or less than approximately 8 mm. In certain further

embodiments, the beveled surface **140** can have a length L_B in a range of approximately 0.1 to approximately 25 mm, approximately 0.5 to approximately 15 mm, or approximately 1 to approximately 8 mm.

In an embodiment, the scintillation pixel **100** can include an alkali halide scintillator, alkaline halide scintillator, lanthanide halide scintillator, elpasolite scintillator, or combinations thereof. In certain embodiments, the scintillation pixel **100** can include NaI(Tl), CsI(Tl or Na), LaBr₃(Ce), CeBr₃, SrI₂(Eu), LuSiO₅(Y and Ce), Cs₂LiYCl₆(Ce), Bi₄Ge₃O₁₂, CdWO₄, Gd₂O₂S(Pr or Ce) or combinations thereof.

Referring now to **FIG. 2**, a reflective material **150** can be disposed along the longitudinally extending surfaces **130**, thereby substantially surrounding the scintillation pixel **100**. The reflective material **150** can include a metal foil, polytetrafluoroethylene (PTFE), a polyester, a white epoxy, or another suitable material capable of reflecting light emitted by the scintillation pixel **100**. The reflective material **150** can be disposed along any desired amount of the longitudinally extending surface **130**. For example, the reflective material **150** can be disposed along substantially all of the length L_L of the longitudinally extending surface **130**, or greater than approximately 25%, greater than approximately 45%, greater than approximately 65%, greater than approximately 85%, or greater than approximately 95% of the length L_L of the longitudinally extending surface **130**. As illustrated in **FIG. 2**, the reflective material **150** can end at the longitudinally surface **130** and be disposed along substantially none of the beveled surface **140**.

In certain other embodiments, as particularly illustrated in **FIG. 3**, the reflective material **150** can continue to extend longitudinally past the beveled surface **140**, thereby creating void space **160** between the reflective material **150** and the beveled surface **140** of the scintillation pixel **100**.

In certain embodiments, as particularly illustrated in **FIG. 4**, the reflective material **150** can also be disposed along a portion of the length L_B of the beveled surface **140**, but less than the entire length of the beveled surface **140**. For example, the reflective material **150** can be disposed along less than approximately 99%, less than approximately 50%, less than approximately 20%, less than approximately 9% along the length L_B of the beveled surface **140**.

In certain embodiments, the reflective material **150** can be disposed along each of the four longitudinally extending surfaces **130** and beveled surfaces **140** as described above. In certain other embodiments, each of the longitudinally extending surfaces **130** or beveled surfaces **140** can have a different amount of reflective material **150** disposed along it. For example, at least one longitudinally extending surface **130** may not have a reflective material **150** disposed along it or can have less than other longitudinally extending surfaces **130**. After reading this specification, skilled artisans will understand that a variety of different patterns of reflective material **150** are within the scope described herein.

Referring now to **FIG. 5**, the proximal end **110** can have a surface area SA_P and the distal end **120** can have a surface area SA_D . The scintillation pixel **100** can have a ratio of the surface area SA_D of the distal end **120** to a surface area SA_P of the proximal end **110** of greater than approximately 0.3:1, greater than approximately 0.5:1, or greater than approximately 0.6:1. The scintillation pixel **100** can have a ratio of the surface area SA_D of the distal end **120** to a surface area SA_P of the proximal end **110** of less than approximately 0.99:1, less than approximately 0.8:1, or less than approximately 0.7:1. The scintillation pixel **100** can have a ratio of the surface area SA_D of the distal end **120** to a surface area SA_P of the proximal end **110** of from approximately 0.3:1 to approximately 0.99:1, approximately 0.5:1 to approximately 0.8:1, or approximately 0.6:1 to approximately 0.7:1.

Referring now to **FIG. 6**, a scintillation pixel **100** has a proximal end **110**, a distal end **120** opposite the proximal end **110**, a longitudinally extending surface **130** adjacent the proximal end **120**, and a beveled surface **140** between the distal end **120** and the longitudinally extending surface **130**. In the embodiment illustrated in **FIG. 6**, at least one longitudinally extending surface **135** is adjacent to both the proximal end **110** and the distal end **120**. In particular embodiments at least one side of the scintillation pixel **100** may not have a beveled surface **140**.

Referring now to **FIG. 7**, a scintillation pixel array **200** has a plurality of scintillation pixels **100** as described in **FIG. 1**. Any scintillation pixel, for example, as described herein, can be arranged in the scintillation array. The scintillation pixel array **200** can contain any number of desired pixels. For example, the scintillation pixel array **200** can contain greater than 2 scintillation pixels, greater than 10, greater than 20, greater than 50, greater than 100, or greater than 200. The scintillation pixel array **200** can have the plurality of scintillation pixels **100** arranged in any desired configuration. In an embodiment, the plurality of scintillation pixels **100** in the pixel array **200** can be arranged in rows and columns.

Referring now to **FIG. 8**, a scintillation pixel array **200** has a plurality of scintillation pixels **100** as described in **FIG. 1** and a reflective material **150** disposed between the longitudinally extending surfaces **130** of at least two scintillation pixels **100**. The reflective material **150** can be disposed about the plurality of the scintillation pixels **100** in any manner described herein.

FIG. 9 illustrates a radiation sensing apparatus **300** in accordance with an embodiment. The radiation sensing apparatus **300** can include, for example, a medical imaging apparatus, a well logging apparatus, a neutron detection apparatus, or a security inspection apparatus. In an embodiment, the radiation sensing apparatus **300** can include or be a component of a Computed Tomography ("CT") apparatus, a Single Positron Emission Computer Tomography ("SPECT") apparatus, or a Positron Emission Tomography ("PET") apparatus, such as a time-of-flight PET apparatus.

The radiation sensing apparatus **300** can include a photon sensor **310**, an optical interface **320**, and a scintillation pixel array **200**. The radiation sensing apparatus **300** can include at least two adjacent scintillation pixels **100** optically coupled to at least two adjacent photon sensors **310**. The

photon sensor **310** can be a photodiode, a photomultiplier tube ("PMT"), a silicon photomultiplier ("SiPM"), an avalanche photodiode ("APD"), or a hybrid PMT that includes a photocathode and an electron sensor. In an embodiment, the optical interface **320** can comprise an optical coupling material, such as an organic polymer or another suitable optical coupling material. For example, the optical coupling material can include a silicone rubber, an epoxy, a plastic, or any combination thereof. The optical coupling material can have a thickness in a range of approximately 0.01 to approximately 10 mm, from approximately 0.05 mm to approximately 6 mm, or from approximately 0.1 mm to approximately 4 mm.

In another embodiment, the optical interface **320** includes a window **330** disposed between the photon sensor **310** and the scintillation pixel **100**. The window **330** can be optically coupled to the photon sensor **310** and the scintillation pixel **100** via an optical coupling material. In an embodiment, the window **330** includes quartz, sapphire, or an aluminum oxynitride. Although the photon sensor **310**, the optical interface **320**, and the scintillation pixel **100** are illustrated as coupled, the photon sensor **310** and the scintillation pixel **100** can each be adapted to be spaced apart from the optical interface **320**, with the optical interface **320** disposed between the photon sensor **310** and the scintillation device **200**. In other embodiments, the optical interface **320** may not include the window **330** and can include one or more layers of optical coupling material. Additionally, the optical interface **320** can include the window **330** and not include the optical coupling material. In certain embodiments, the window can have a thickness in a range of approximately 0.1 mm to approximately 35 mm or approximately 1 mm to approximately 25 mm.

The optical interface can be substantially clear. In an embodiment, the plurality scintillation pixels **100** can have an index of refraction, and the optical interface **320** can have one or more indexes of refraction that are different from the index of refraction of the scintillation pixel **100**. For example, the window **330**, one of a plurality of layers of the optical coupling material, or combinations thereof, can have an index of refraction that is different from the index of refraction of the scintillation pixel **100**. In a particular embodiment, one or more of the indexes of refraction of the optical interface **320**, the window **330**, or any combination thereof can have a lower index of refraction than the index of refraction of the scintillation pixel **100**.

The photon sensor **310** can have a surface area of the top surface. In certain embodiments, a ratio of the surface area of a light receiving surface of the photon sensor to a surface area of the distal end of the scintillation pixel can be in a range of greater than approximately 1:1 to approximately 10:1, from approximately 1.5:1 to approximately 5:1, or from approximately 1.5:1 to approximately 3:1.

The radiation sensing apparatus **300** can further include a shock absorbing member. The scintillation pixel **100**, the reflector **150**, and the shock absorbing member can be housed within a casing. The casing can include a stabilization mechanism, such as a spring, an elastomer, another

suitable stabilization mechanism, or any combination thereof, interfaced to an end of the scintillation pixel **100** that is distal from the photon sensor **310**. In an embodiment, the radiation sensing apparatus **300** can include more components or fewer components than those shown in **FIG. 9**. For example, radiation sensing apparatus **300** may not include the stabilization mechanism or the radiation sensing apparatus **300** can include multiple stabilization mechanisms, such as multiple springs. In another example, the scintillation pixel **100** can be partially surrounded by the reflector **150**, for example, in any manner described herein.

The photon sensor **310** can receive photons of scintillating light emitted by the scintillation pixel **100** when the scintillation pixel **100** is exposed to one or more forms of radiation. When the photon sensor **310** receives photons from the scintillation pixel **100**, the photon sensor **310** can produce electrical pulses based on numbers of photons received from the scintillation array **200**. The photon sensor **310** can provide the electrical pulses to electronics that are electrically coupled to the photon sensor **310**. The electrical pulses can be shaped, digitized, analyzed, or any combination thereof, by the electronics to provide a count of the photons received at the photon sensor **310** or other information. The electronics can include an amplifier, a pre-amplifier, a discriminator, an analog-to-digital signal converter, a photon counter, another electronic component, or any combination thereof. The photon sensor **310** can be housed within a tube or housing made of a material capable of protecting the photon sensor **310**, the electronics, or a combination thereof, such as a metal, a metal alloy, other material, or any combination thereof.

In certain embodiments, as particularly illustrated in **FIG. 10**, the radiation sensing apparatus **300** can further include a mask **330** disposed between the distal end **120** of the scintillation pixel **100** and the optical interface **320**. The mask **330** can be disposed around the periphery of the distal end **120** thereby leaving an opening **340** in the center of the distal end **120**. For example, the mask **330** can cover less than 50%, less than 40%, less than 30%, less than 20%, or less than 10% of the surface area of the distal end **120**. As illustrated in **FIG. 10**, in embodiments having a mask **330**, there can be no beveled surfaces on the scintillation pixel **100**. In certain other embodiments, the scintillation pixel **100** can have both beveled surfaces **140** and a mask **330**. The mask **330** can be made of any material capable of absorbing a photon. For example, the mask **330** can include graphite, carbon black, or ferrous ferric oxide. Similar to the beveling, having a mask **330** disposed as described increases the distance between the point at which a photon exits the scintillation pixel **100** and the surface of an adjacent photon sensor, thereby reducing the probability of cross-talk occurring.

Cross-talk can occur when photons that exit a first scintillation pixel are attributed to a second scintillation pixel when the photons are sensed by a second photon sensor that does not correspond to the first scintillation pixel. When a photon that exits a first scintillation pixel and is sensed by the nearest photon sensor, it is said to be corresponding. When a photon that exits a first scintillation pixel and is sensed by a photon sensor other than the corresponding sensor, it is said to be non-

corresponding. One reason for the photons exiting the first scintillation pixel being sensed by the second photon sensor instead of the first photon sensor can be the difference in refraction index of the scintillation pixel and the optical coupling material. Photons exiting the scintillation pixel will spread out in the optical interface before being sensed by the desired photon sensor. In particular, when the optical interface has a lower index of refraction than the scintillation pixel, the angle at which the photons spread out will become more oblique. Photons deflected at the more oblique angle can have a higher probability of being sensed by an undesired photon sensor. Cross-talk contributes to increased blurring of the final image produced in, for example, a medical imaging device.

A radiation sensing apparatus including the scintillation pixel array described herein can have a reduced amount of cross-talk that occurs between scintillation pixels. For example, the arrangement of the scintillation pixel having a beveled surface combined with the arrangement of the reflector described herein concentrate the photons exiting the scintillation pixel within a central region of the distal end of the scintillation pixel. One way cross-talk can be reduced with the embodiments described herein is by increasing the distance a photon must travel to be sensed by an adjacent photon sensor. Increasing this distance decreases the probability that the photon will be sensed by a non-targeted photon sensor. Another way to reduce cross talk with the embodiments described herein is the combination of beveled surfaces and the reflector arrangements as described herein which can have the effect of deflecting the photon trajectories toward the center of the scintillation pixel, forcing the cross-talk distance to be even longer. With the radiation sensing device described herein, the cross talk between adjacent scintillation pixels can be less than approximately 5%, less than approximately 3%, or less than approximately 0.9%. By reducing the cross-talk with the embodiments described herein, the optical interface does not have to be reduced in thickness, or the optical interface material can have a greater index of refraction, or any combination thereof.

Another aspect of the present disclosure relates to a method of making a scintillation pixel array as described herein. The method can include providing a plurality of scintillation pixels. At least one scintillation pixel of the plurality of scintillation pixels has a proximal end, a distal end opposite the proximal end, and a longitudinally extending surface adjacent the proximal end. In certain embodiments, the plurality of scintillation pixels may be formed, such as, for example, cut from a single crystal. In such embodiments, the single crystal can be cut laterally one or more times and longitudinally one or more times to form a plurality of scintillation pixels. A variety of different number of scintillation pixels may be provided in accordance with the description herein.

The method also includes forming a bevel surface adjacent the distal end. The forming of the bevel surface can include, milling, polishing, cleaving, cutting, growing, etching, extruding, casting or combinations thereof. For example, in certain embodiments, the bevel surface can be epitaxially grown on the surface of the scintillation pixel, such as by a hydride vapor phase epitaxy (HVPE) process, metal organic chemical vapor deposition (MOCVD) process or any combination

thereof. In certain other embodiments, the beveled surface may be formed by cutting the scintillation pixel at angle relative to the distal end 120. In such embodiments, more than one scintillation pixel may have a beveled surface formed therein with the same cut. For example, in an arrangement of a 3x3 scintillation pixel array in rows and columns, only 12 cuts would be required to form beveled surfaces on all of the scintillation pixels. In certain embodiments, more than one method may be used to form a beveled surface on the same or different pixels within a pixel array.

The method further includes providing a reflective material along the longitudinally extending surface. The reflective material can be disposed in any configuration described herein. For example, in certain embodiments, the reflective material can be adjacent to less than approximately 99% of the beveled surface. In other examples, the reflective material can continue to extend laterally past the start of the beveled surface thereby having void space between the reflective material and the scintillation pixel. In certain embodiments, the providing of the reflective material can be performed before or after forming the beveled surface. The reflective material can be a unitary piece of material or may be a plurality of different pieces. Furthermore, in certain embodiments, the reflective material can be a sleeve. In further embodiments, the reflective material may comprise a powder material.

The method further includes arranging the plurality of scintillation pixels in an array. The forming of the bevel surface can be performed before or after arranging the plurality of scintillation pixels in an array. Moreover, in certain embodiments, the providing of the reflective material can be performed before or after arranging the plurality of scintillation pixels in an array. In certain embodiments, the scintillation pixels can be arranged in a configuration of rows and columns. The scintillation pixels may be in contact with the reflective material or may be spaced apart from the reflective material. In certain embodiments, two opposite sides of the same reflective material can be in contact with two different scintillation pixels at the same time.

Many different aspects and embodiments are possible. Some of those aspects and embodiments are described herein. After reading this specification, skilled artisans will appreciate that those aspects and embodiments are only illustrative and do not limit the scope of the present invention.

In a first aspect, a scintillation pixel array comprises a plurality of scintillation pixels, wherein at least one scintillation pixel of the plurality of scintillation pixels has a proximal end, a distal end opposite the proximal end, a longitudinally extending surface adjacent the proximal end, and a beveled surface between the distal end and the longitudinally extending surface; and a reflective material disposed along the longitudinally extending surface and less than approximately 99% of the beveled surface.

In an embodiment of the first aspect, the reflective material is disposed along a portion of or all of the longitudinally extending surfaces and along only a portion or substantially none of the angled surface.

In an embodiment of the first aspect, the beveled surface forms an angle of from greater than 90° to less than 180°, or from approximately 105° to approximately 165°, or from approximately 120° to approximately 150°, or from approximately 130° to approximately 140° with the distal end.

5 In a second aspect, a radiation sensing apparatus comprises the scintillation pixel array of the first aspect and a photon sensor optically coupled to the at least one of the plurality of scintillation pixels, wherein the distal end is adjacent to the photon sensor.

10 In an embodiment of the first aspect, the radiation sensing apparatus comprises an optical coupling material between the distal end and the photon sensor. In another embodiment, the optical coupling material is substantially clear. In another embodiment, the optical coupling material comprises silicone rubber. In another embodiment, the optical coupling material comprises an epoxy.

In another embodiment of the second aspect, the radiation sensing apparatus further comprises at least two adjacent scintillation pixels optically coupled to at least two adjacent photon sensors.

15 In another embodiment of the second aspect, cross talk between adjacent scintillation pixels is less than approximately 5%, less than approximately 3%, or less than approximately 0.9%.

In another embodiment of the first or second aspect, a medical imaging device comprises the scintillation pixel array or the radiation sensing apparatus.

20 In a third aspect, a method of making a scintillation pixel array comprises: providing a plurality of scintillation pixels, wherein at least one scintillation pixel of the plurality of scintillation pixels has a proximal end, a distal end opposite the proximal end, and a longitudinally extending surface adjacent the proximal end; forming a bevel surface adjacent the distal end; providing a reflective material along the longitudinally extending surface; and arranging the plurality of scintillation pixels in an array; wherein the reflective material is adjacent to less than approximately 99% of the beveled surface.

25 In an embodiment of the second aspect, forming the beveled surface is performed before arranging the plurality of scintillation pixels in an array. In another embodiment of the second aspect, forming the beveled surface is performed after arranging the plurality of scintillation pixels in an array. In another embodiment of the second aspect, the beveled surface is formed by milling or polishing. In another embodiment of the second aspect, the beveled surface is formed by cleaving.

30 In another embodiment of any of the first, second, or third aspects, the reflective material is disposed between the longitudinally extending surfaces of at least two scintillation pixels.

In another embodiment of any of the first, second, or third aspects, the at least one of the plurality of scintillation pixels has four longitudinally extending surfaces between the proximal end and the beveled surface, and wherein the reflective material is disposed along each of the four
35 longitudinally extending surfaces and less than approximately 99%, less than approximately 50%, less than approximately 20%, less than approximately 9%, or substantially none of the beveled surface.

In a fourth aspect, a scintillation apparatus comprises a single scintillator having a proximal end, a distal end opposite the proximal end, a longitudinally extending surface adjacent the proximal end, and a beveled surface between the distal end and the longitudinally extending surface; and a reflective material disposed along the longitudinally extending surface and less than approximately 99% of the beveled surface.

In another embodiment of any of the first, second, third, or fourth aspects, the reflective material extends less than approximately 50%, less than approximately 20%, or less than approximately 9% of the beveled surface.

In another embodiment of any of the first, second, third, or fourth aspects, the reflective material extends to substantially none of the beveled surface.

In another embodiment of any of the first, second, third, or fourth aspects, at least one longitudinally extending surface is adjacent to the distal end.

In another embodiment of any of the first, second, third, or fourth aspects, the at least one scintillation pixel has a ratio of a surface area of the distal end to the surface area of the proximal end of from approximately 0.3:1 to approximately 0.99:1, approximately 0.5:1 to approximately 0.8:1, or approximately 0.6:1 to approximately 0.7:1.

In another embodiment of any of the first, second, third, or fourth aspects, a void space is between the reflective material and the beveled surface.

In another embodiment of any of the first, second, third, or fourth aspects, a ratio of the surface area of a light receiving surface of the photon sensor to a surface area of the distal end of the scintillation pixel is in a range of greater than approximately 1:1 to approximately 10:1, from approximately 1.5:1 to approximately 5:1, or from approximately 1.5:1 to approximately 3:1.

EXAMPLES

The concepts described herein will be further described in the following examples, which do not limit the scope of the invention described in the claims. Some of the parameters below have been approximated for convenience.

Example 1: Comparison of Radiation Sensing Apparatus in accordance with an embodiment described herein and a radiation sensing apparatus without a bevel edge.

Two scintillation pixels arrays having a 3x3 arrangement of LYSO pixels and a pixel size of 5 mm height, 5 mm width, and 5 mm length were tested in a simulation for cross talk and collection efficiency. The first scintillation pixel array (A) is a standard pixel having no beveled surfaces and a reflector substantially covering the entire longitudinally extending surfaces of the pixel. The second scintillation pixel array (B) is a pixel array as described herein having a 135° angled beveled surface over the last 1 mm and a reflector extending longitudinally along the substantially the entire length of scintillation pixel. The reflector on both arrays was diffuse RC=0.97

The results are displayed below in Table 1 and the simulation images for A and B are illustrated in **FIG. 11** and **FIG. 12** respectively.

Table 1:

Property	A (comparison)	B
Cross-talk	5.4%	0.9%
Collection Efficiency	87%	76%

Note that not all of the activities described above in the general description or the examples are required, that a portion of a specific activity may not be required, and that one or more further activities can be performed in addition to those described. Still further, the order in which activities are listed is not necessarily the order in which they are performed.

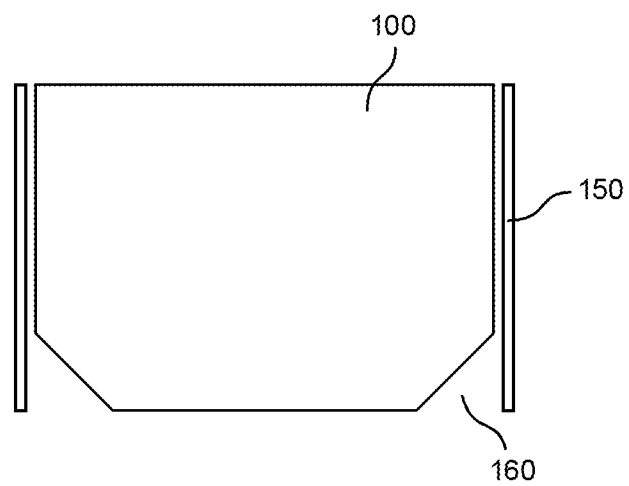
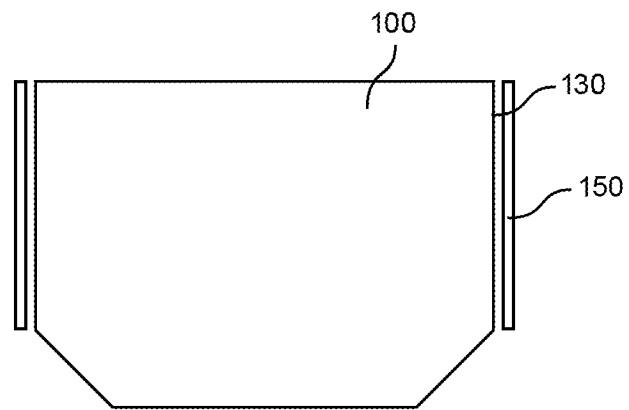
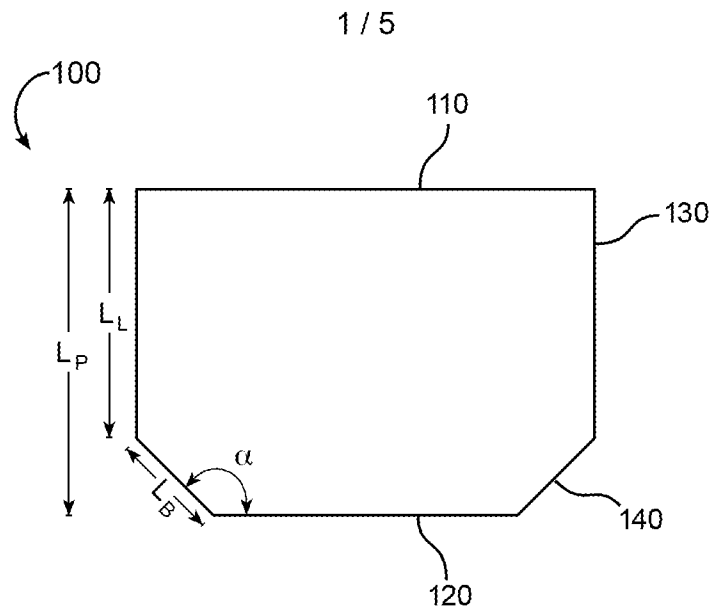
Certain features that are, for clarity, described herein in the context of separate embodiments, can also be provided in combination in a single embodiment. Conversely, various features that are, for brevity, described in the context of a single embodiment, can also be provided separately or in any subcombination. Further, reference to values stated in ranges includes each and every value within that range.

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that can cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims.

WHAT IS CLAIMED IS:

1. A scintillation pixel array comprising:
 - a plurality of scintillation pixels, wherein at least one scintillation pixel of the plurality of scintillation pixels has a proximal end, a distal end opposite the proximal end, a longitudinally extending surface adjacent the proximal end, and a beveled surface between the distal end and the longitudinally extending surface; and
 - a reflective material disposed along the longitudinally extending surface and less than approximately 99% of the beveled surface.
2. The scintillation pixel array of claim 1, wherein the reflective material is disposed along a portion of or all of the longitudinally extending surfaces and along only a portion or substantially none of the angled surface.
3. The scintillation pixel array of claim 1, wherein the beveled surface forms an angle of from greater than 90° to less than 180°, or from approximately 105° to approximately 165°, or from approximately 120° to approximately 150°, or from approximately 130° to approximately 140° with the distal end.
4. A radiation sensing apparatus comprising the scintillation pixel array of one of claims 1-3 and a photon sensor optically coupled to the at least one of the plurality of scintillation pixels, wherein the distal end is adjacent to the photon sensor.
5. The radiation sensing apparatus of claim 4 further comprising an optical coupling material between the distal end and the photon sensor.
6. The radiation sensing apparatus of any one of claims 4-5 further comprising at least two adjacent scintillation pixels optically coupled to at least two adjacent photon sensors.
7. The radiation sensing apparatus of any one of claims 4-5 wherein cross talk between adjacent scintillation pixels is less than approximately 5%, less than approximately 3%, or less than approximately 0.9%.
8. A method of making a scintillation pixel array comprising:
 - providing a plurality of scintillation pixels, wherein at least one scintillation pixel of the plurality of scintillation pixels has a proximal end, a distal end opposite the proximal end, and a longitudinally extending surface adjacent the proximal end;
 - forming a bevel surface adjacent the distal end;
 - providing a reflective material along the longitudinally extending surface; and
 - arranging the plurality of scintillation pixels in an array;
 - wherein the reflective material is adjacent to less than approximately 99% of the beveled surface.

9. The scintillation pixel array, the radiation sensing apparatus, or the method of any one of the preceding claims, wherein the reflective material is disposed between the longitudinally extending surfaces of at least two scintillation pixels.
10. The scintillation pixel array, the radiation sensing apparatus, or the method of any one of the preceding claims, wherein the at least one of the plurality of scintillation pixels has four longitudinally extending surfaces between the proximal end and the beveled surface, and wherein the reflective material is disposed along each of the four longitudinally extending surfaces and less than approximately 99%, less than approximately 50%, less than approximately 20%, less than approximately 9%, or substantially none of the beveled surface.
11. A scintillation apparatus comprising:
 - a single scintillator having a proximal end, a distal end opposite the proximal end, a longitudinally extending surface adjacent the proximal end, and a beveled surface between the distal end and the longitudinally extending surface; and
 - a reflective material disposed along the longitudinally extending surface and less than approximately 99% of the beveled surface.
12. The scintillation pixel array, the radiation sensing apparatus, the scintillation apparatus or the method of any one of the preceding claims, wherein the reflective material extends less than approximately 50%, less than approximately 20%, or less than approximately 9% of the beveled surface.
13. The scintillation pixel array, the radiation sensing apparatus, the scintillation apparatus or the method of any one of the preceding claims, wherein the reflective material extends to substantially none of the beveled surface.
14. The scintillation pixel array, the radiation sensing apparatus, the scintillation apparatus or the method of any one of the preceding claims, wherein the at least one scintillation pixel has a ratio of a surface area of the distal end to the surface area of the proximal end of from approximately 0.3:1 to approximately 0.99:1, approximately 0.5:1 to approximately 0.8:1, or approximately 0.6:1 to approximately 0.7:1.
15. The scintillation pixel array, the radiation sensing apparatus, the scintillation apparatus or the method of any one of the preceding claims, wherein a void space is between the reflective material and the beveled surface.



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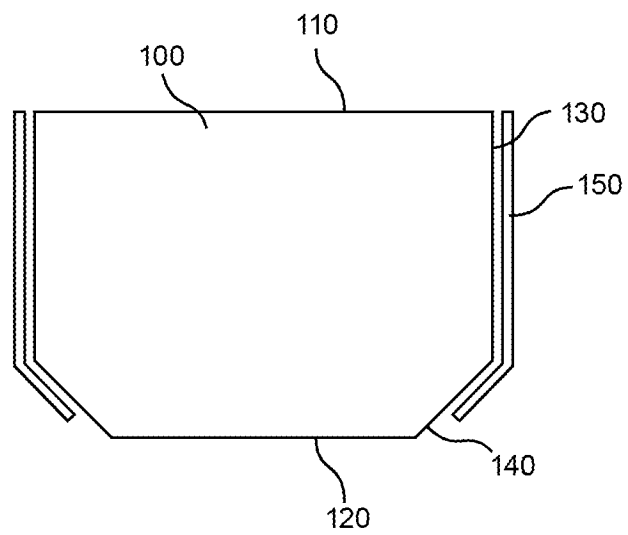


FIG. 4

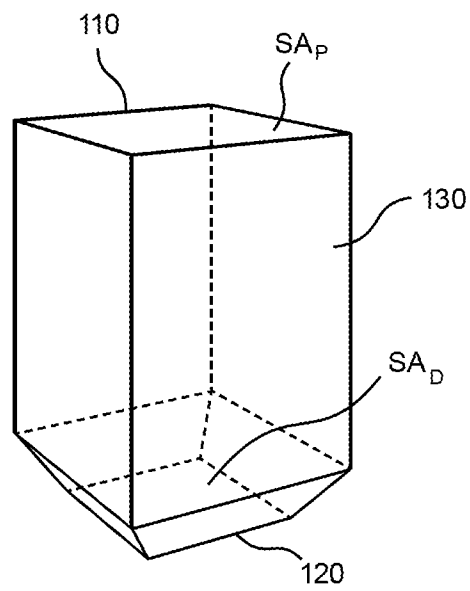


FIG. 5

3 / 5

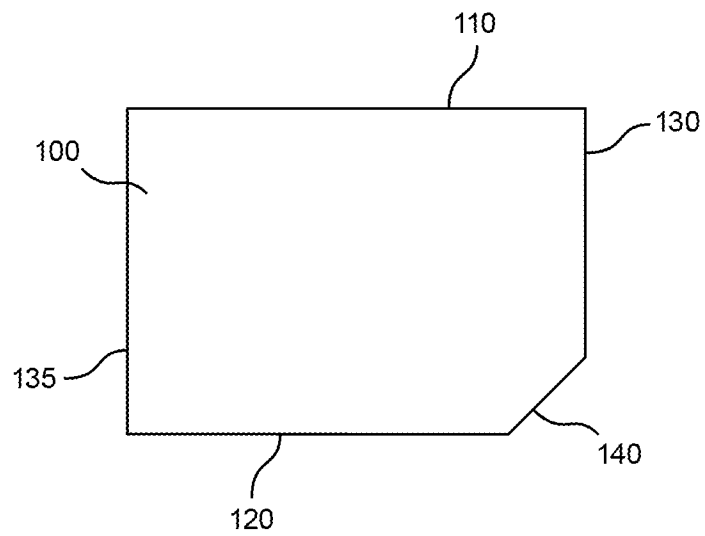


FIG. 6

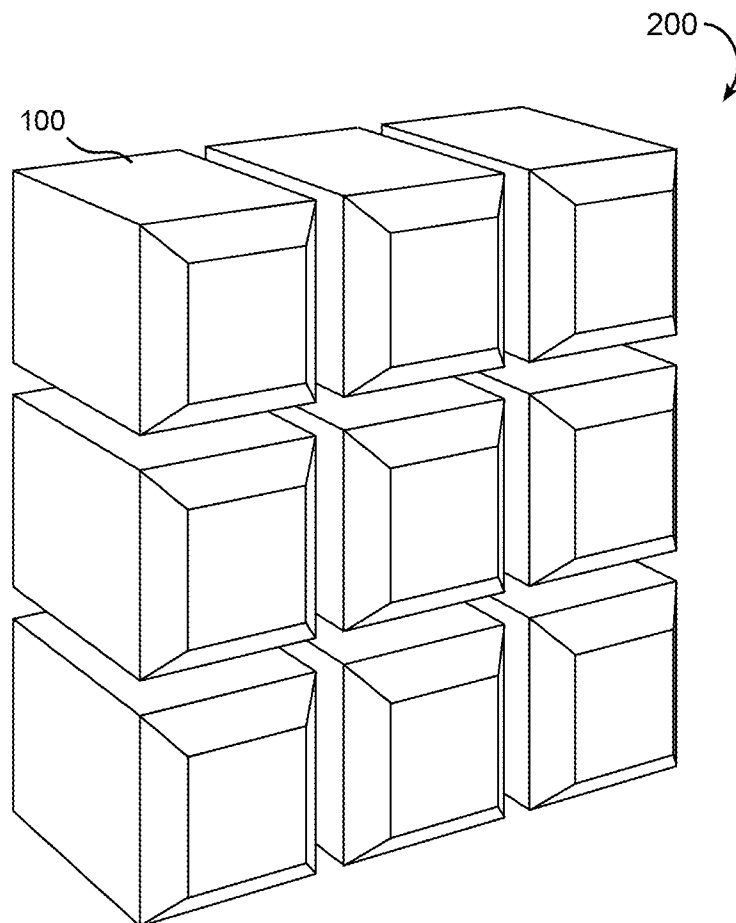


FIG. 7

4 / 5

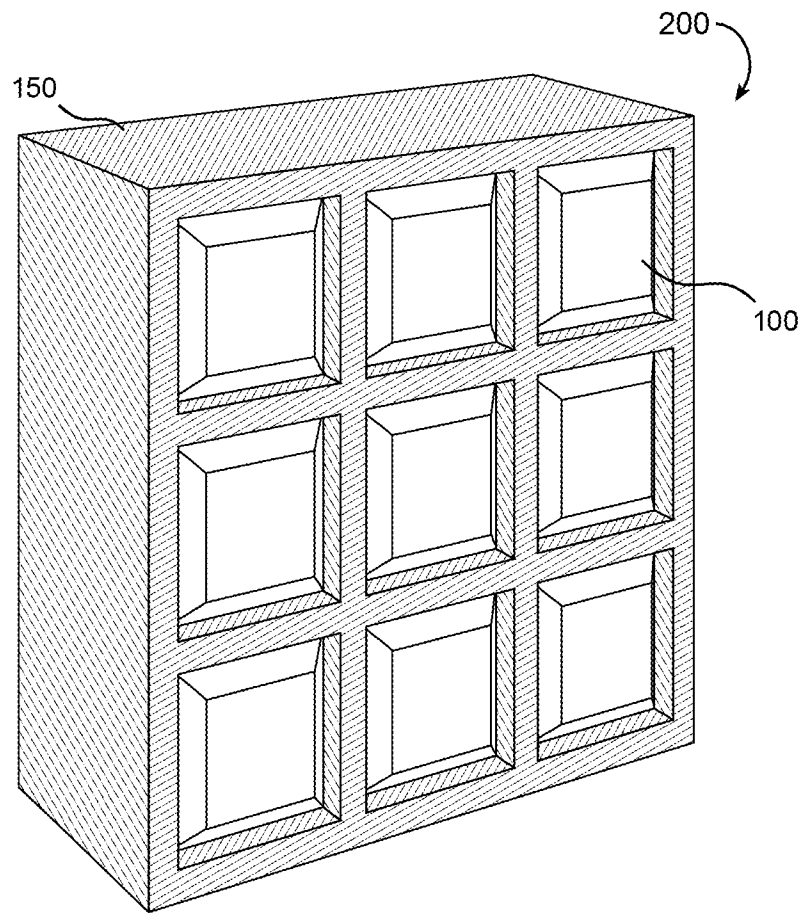


FIG. 8

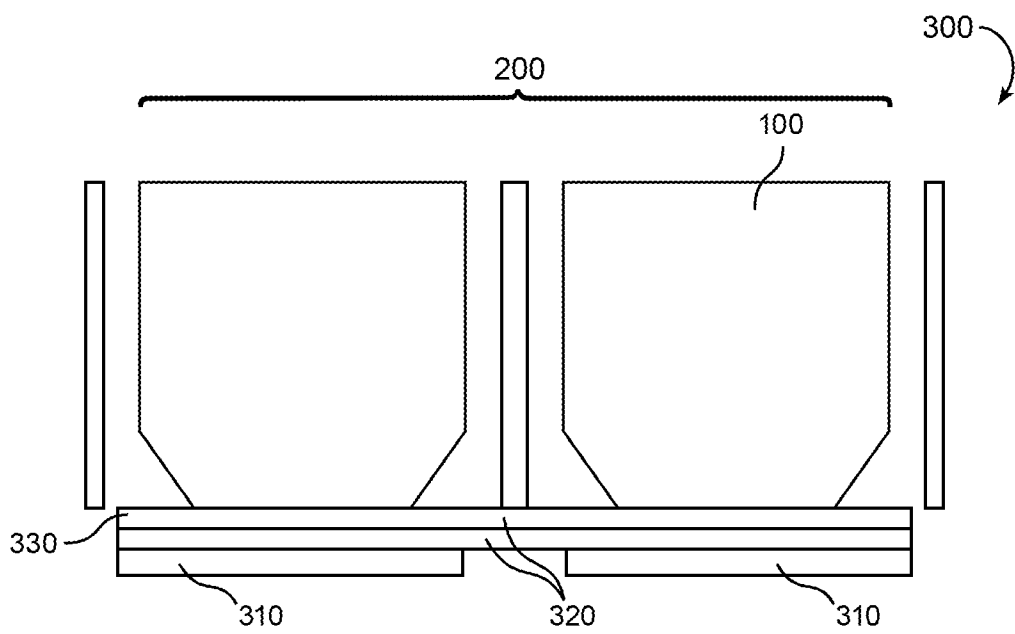


FIG. 9

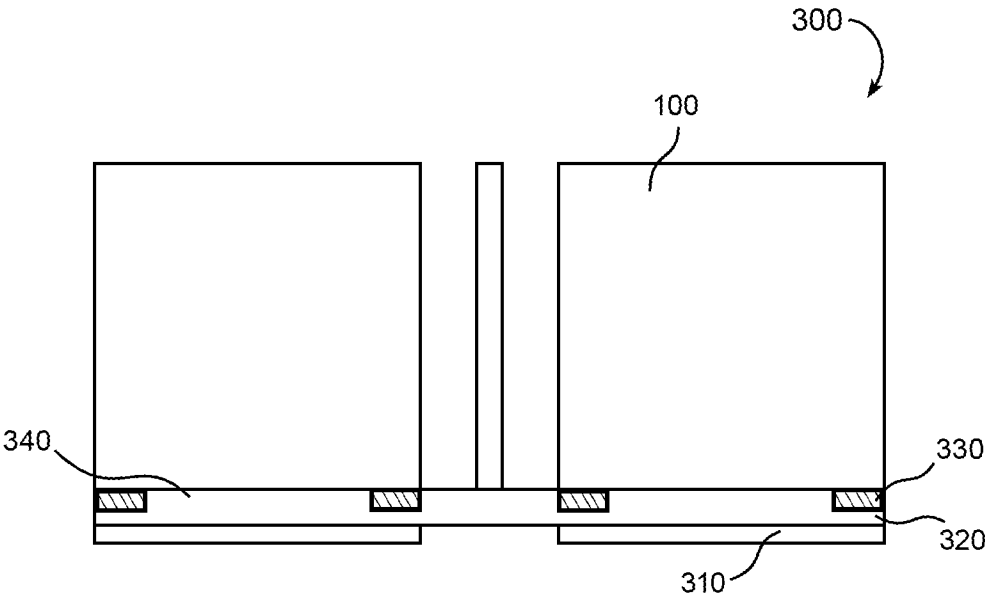


FIG. 10

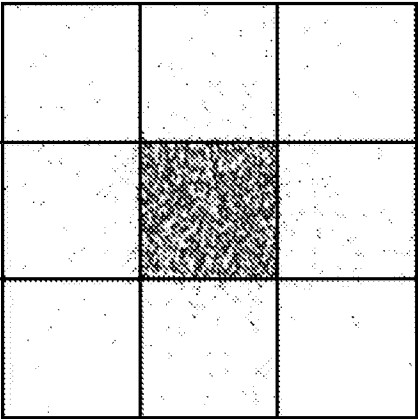


FIG. 11

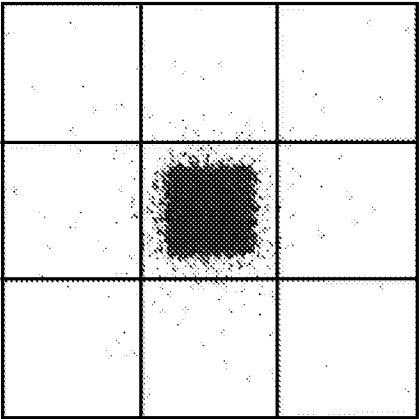


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/059514**A. CLASSIFICATION OF SUBJECT MATTER****G01T 1/20(2006.01)i, H01L 27/14(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01T 1/20; G01T 1/202; G01N 21/36; H01L 27/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: scintillation, pixel, reflective, beveled, taper, and array

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005-0104000 A1 (KINDEM et al.) 19 May 2005 See abstract; paragraphs 27-41 and figures 1-2C.	1-5, 8, 11
A	US 2010-0148074 A1 (MENGE et al.) 17 June 2010 See abstract; paragraphs 29-47 and figures 1-7.	1-5, 8, 11
A	WO 2011-060166 A2 (SAINT-GOBAIN CERMICS & PLASTICS, INC.) 19 May 2011 See abstract; pages 6-11 and figures 1-11.	1-5, 8, 11
A	US 6921909 B2 (NAGARKAR et al.) 26 July 2005 See abstract; column 6, line 36 - column 9, line 51 and figures 1-5.	1-5, 8, 11
A	US 2009-0294683 A1 (PERNA, LOUIS) 03 December 2009 See abstract; paragraphs 24-34 and figures 1-4B.	1-5, 8, 11



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 December 2013 (10.12.2013)

Date of mailing of the international search report

10 December 2013 (10.12.2013)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2013/059514**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 6,7,9,10, and 12-15
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/059514

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